

LCA Case Studies

Life Cycle Assessment of Cane-Sugar on the Island of Mauritius

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Abstract

Goal, Scope and Background. Agricultural production includes not only crop production, but also food processing, transport, distribution, preparation, and disposal. The effects of all these must be considered and controlled if the food chain is to be made sustainable. The goal of this case study was to identify and review the significant areas of potential environmental impacts across the whole life cycle of cane sugar on the island of Mauritius.

Methods. The functional unit was one tonne of exported raw sugar from the island. The life cycle investigated includes the stage of cane cultivation and harvest, cane burning, transport, fertilizer and herbicide manufacture, cane sugar manufacture and electricity generation from bagasse. Data was gathered from companies, factories, sugar statistics, databases and literature. Energy depletion, climate change, acidification, oxidant formation, nitrification, aquatic ecotoxicity and human toxicity were assessed.

Results and Discussion. The inventory of the current sugar production system revealed that the production of one tonne of sugar requires, on average, a land area of 0.12 ha, the application of 0.84 kg of herbicides and 16.5 kg of N-fertilizer, use of 553 tons of water and 170 tonne-km of transport services. The total energy consumption is about 14235 MJ per tonne of sugar, of which fossil fuel consumption accounts for 1995 MJ and the rest is from renewable bagasse. 160 kg of CO₂ per tonne of sugar is released from fossil fuel energy use and the net avoided emissions of CO₂ on the island due to the use of bagasse as an energy source is 932,000 tonnes. 1.7 kg TSP, 1.21 kg SO₂, 1.26 kg NO_x and 1.26 kg CO are emitted to the air per tonne of sugar produced. 1.7 kg N, 0.002 kg herbicide, 19.1 kg COD, 13.1 kg TSS and 0.37 kg PO₄³⁻ are emitted to water per tonne of sugar produced. Cane cultivation and harvest accounts for the largest environmental impact (44%) followed by fertilizer and herbicide manufacture (22%), sugar processing and electricity generation (20%), transportation (13%) and cane burning (1%). Nitrification is the main impact followed by acidification and energy depletion.

Conclusions. There are a number of options for improvement of the environmental performance of the cane-sugar production chain. Cane cultivation, and fertilizer and herbicide manufacture, were hotspots for most of the impact categories investigated. Better irrigation systems, precision farming, optimal use of herbicides, centralisation of sugar factories, implementation of co-generation projects and pollution control during manufacturing and bagasse burning are measures that would considerably decrease resource use and environmental impacts.

Recommendation and Outlook. LCA was shown to be a valuable tool to assess the environmental impacts throughout the food production chain and to evaluate government policies on agricultural production systems.

Keywords: Agriculture; cane sugar; case studies; food production systems, bagasse; Mauritius

Introduction

Farmers and farm workers in more than 110 countries grow enough sugar cane and sugar beet to provide 20 kg of sugar per capita per year, which is equivalent to about 13 per cent of all energy derived from food. Despite competitive pressure in the sweetener market, sugar still accounts for about 85 per cent of the world sweetener market. The 80 or so cane growing countries are gradually increasing their share of world production, which now reaches about 73 percent. The small island of Mauritius is among the ten largest sugar exporters. Mauritius provide a special case in development, largely due to special characteristics of their natural, economic and social environment. Understanding and implementing strategies for sustainable development become critical issues for islanders. The island has evolved from an agricultural to a semi-industrialised country over the past 3 decades with the sugar industry still occupying a prominent position in the economy. Sugar cane covers 40% of the island's total area of about 2000 square kilometres, or approximately 80% of the cultivated land. The sugar industry employs about 20% of the labour force and accounts for 10% of the GDP. Socio-economically, the sugar industry is a highly important crop in Mauritius. The main data pertaining to the industry in 2000 are summarised in Table 1. The sugar production during the 2000 crop season was relatively low and the country had to import sugar from South Africa to meet the local consumption, and thus be able to meet the various export quotas with the local sugar production.

Table 1: The 2000 cane-sugar production in Mauritius (MSIRI 2000)

| | |
|--|-----------|
| Cultivation | |
| Area cultivated (ha) | 75,133 |
| Cane production (tonnes) | 5,109,521 |
| Cane yield per hectare (tonnes/ha) | 69.9 |
| Harvest: Cane mechanically harvested | 9% |
| Cane mechanically loaded | 50% |
| Milling | |
| Number of sugar factories operating | 14 |
| Tonnes cane crushed | 5,105,700 |
| Tonnes sugar produced | 570,844 |
| Average yield of sugar per hectare (tonnes/ha) | 8 |
| Commercial sugar recovered, % cane | 11 |
| Exportation | |
| Total sugar exported (tonnes) | 570,992 |
| Local sugar consumption (tonnes) | 39,000 |
| Others | |
| Number of employees | 32,800 |
| Surplus electricity production (GWh) | 360 |
| Molasses production (tonnes) | 124,713 |
| Alcohol production (litres) | 5,738,601 |

The sugar cane industry has been undergoing increasing pressure due to sugar price stagnation and the rising cost of sugar production. These pressures have instigated a number of actions to improve efficiency and diversify its activities both at the field and factory levels, with the ultimate objective being to increase revenue through improvement in efficiency in sugar production with a concurrent reduction in cost of production. These call for a more intensive and efficient exploitation of available resources – for example: mechanization of cultural operations to overcome labour shortage, centralization of cane milling operations and increasing exploitation of bagasse for energy purposes (MOA, 2001). Such developments may lead to profound changes which are likely to have strong repercussions and need to be addressed properly in terms of impact on the environment.

Agricultural production includes not only crop production but also food processing, transport, distribution, preparation and disposal. The effects of all these must be considered and controlled if the food chain is to be made sustainable. Besides energy, other important resources needed in the food production system are land, water and nutrients (Mattsson 1996). Government agricultural and energy policies will have enormous effects on agricultural production systems and their subsequent environmental impacts. Tools to evaluate strategies and monitor progress are required. LCA is a useful tool for examining environmental impacts through-

out the food production chain and can be used as a 'compass' to show the direction towards sustainability. So far, there have been only a few LCAs that have attempted to cover entire food systems. Andersson (2000) and Andersson et al. (1994) give an overview of the LCAs of food products.

1 Goal and Scope Definition

The goal is to identify and review the significant areas of potential environmental impacts across the whole life cycle of cane sugar. The objectives of this study are to:

- Examine the total life cycle of cane-sugar and to identify the stages with the largest environmental impacts, the 'hot spots' of the life cycle,
- establish an inventory analysis of raw materials, energy flows and waste outputs for the currently practiced cane-sugar production chain,
- recommend responses for a sustainable system.

1.1 Functional unit

The functional unit was set to one tonne of raw cane sugar exported from the island.

1.2 System definition

System boundaries for agriculture have been extensively discussed in Audsley et al. (1997). The steps of the life cycle of cane-sugar production included in the study are shown in a flow chart (Fig. 1). The boundary encompasses cane pro-

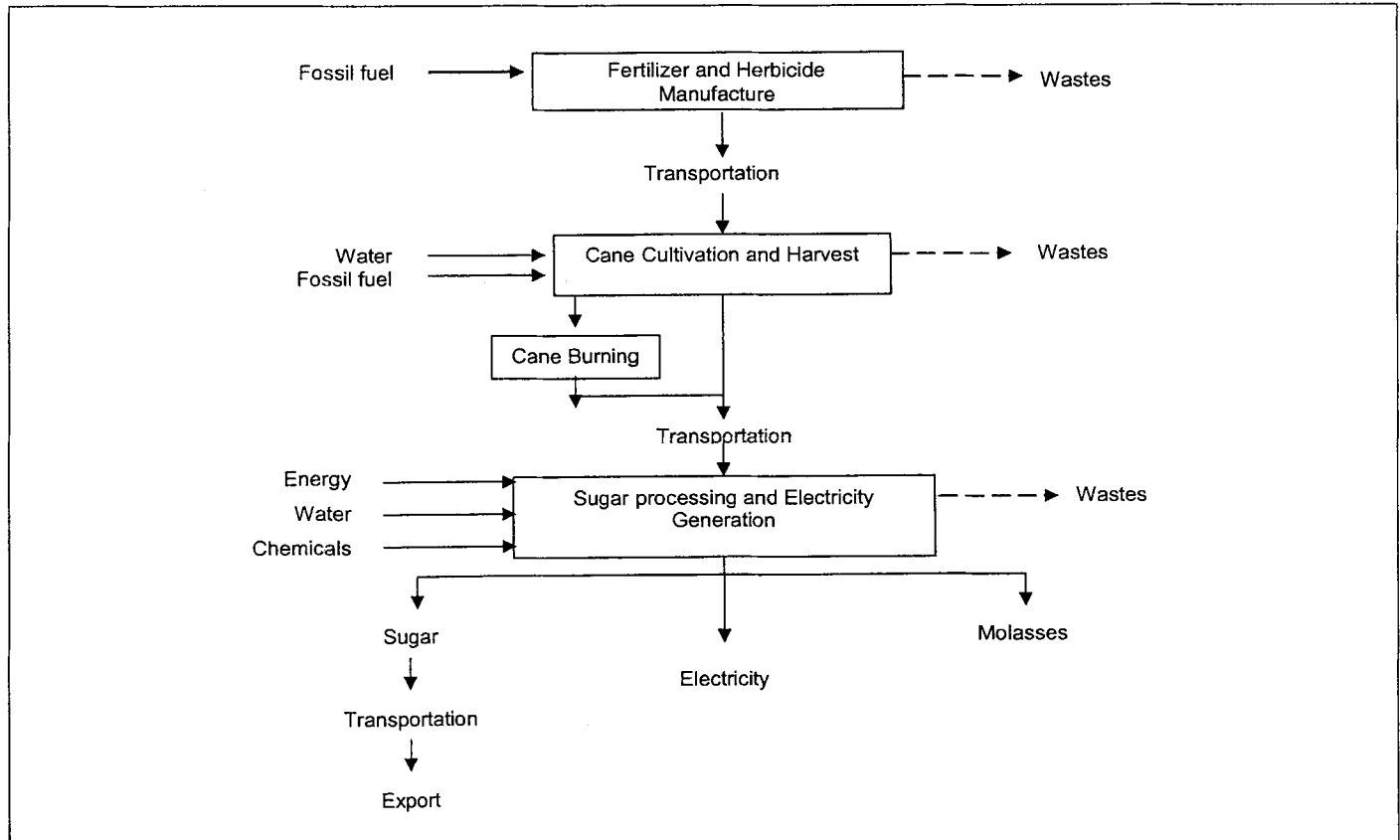


Fig. 1: Process Flow chart for the life cycle of cane sugar

duction and harvest, cane burning, transportation, fertilizer and herbicide manufacture, and sugar processing and electricity generation. The production of sugar over the whole island was considered and the system is intended to be representative of current agricultural techniques and manufacturing processes in the Mauritian Sugar industry. The following systems were excluded:

- Consumption of sugar on the island,
- capital costs (manufacture, maintenance and decommissioning of capital equipment and capital goods, machinery, buildings, etc.),
- general infrastructures, accidents, human resources,
- interaction between crops in interline cropping,
- land use and soil quality changes caused by cultivation.

The main data sources for the five subsystems are provided in Table 2. Table 3 summarizes the main assumptions made in the study.

Table 2: The five stages of the life cycle of cane sugar and their data sources

| | Life cycle | Processes | Sources of data |
|---|---|---|--|
| 1 | Cane cultivation and Harvest | <ul style="list-style-type: none"> • Machine time hours • Tractor fuel consumption • Irrigation • Herbicides and fertilizers application • Cane harvest • Nutrient leaching and emissions | Mann and Spath (1995) Borjesson (1996), Boever and Meyer (1984) Ramjeawon (1994) MSIRI (2001) Meyer (1998), De Beer et al. (1993) MSIRI (2001), Brentrup et al (2000), Ng Kee Kwong and Deville (1984), Ng Kee Kwong (1995), Umrit et al.(1992) |
| 2 | Cane Burning | <ul style="list-style-type: none"> • Emissions | US EPA (1995) |
| 3 | Transportation | <ul style="list-style-type: none"> • Cane transport • Fertiliser transport • Herbicide transport • Sugar transport | Jacquin and Poser (1994), Boever and Meyer (1984) UNEP (1996) UNEP (1996) |
| 4 | Fertilizer and Herbicide Manufacture | <ul style="list-style-type: none"> • Herbicide Manufacture • Fertiliser Manufacture | OECD (1994), Borjesson (1996) Marland and Turhollow (1991), Economopoulos (1993) |
| 5 | Sugar Processing and Electricity Generation | <ul style="list-style-type: none"> • Water Consumption • Waste generation • Electricity generation | Ramjeawon T and Baguant J (1996), NRI (1995) Ramjeawon T (2000), MSA (1994) Deepchand (2000) |

Table 3: Subsystems and main assumptions

| | Subsystem | Assumptions |
|---|--|---|
| 1 | Cane Cultivation and Harvest | <ul style="list-style-type: none"> • 1 hectare = 75.8 tonnes of cane = 8.35 tonnes of sugar • Cultivation area of 78000 ha • Cultivation with a seven-year plant cycle • 315 Mm³ of irrigation water • Electricity consumption of 216 kWh/ha for irrigation • N₂O emissions from soil – 1.25% of nitrogen input • NO_x emissions from soil – 0.5% of nitrogen input • 138 KgN, 50 kg P₂O₅ and 175 kg K₂O applied per ha • 7.8 kg a.i of herbicides applied per ha • 10% of nitrogen and 0.2% of herbicides lost in water bodies • 1 kg of phosphorus lost in surface runoffs per ha |
| 2 | Cane Burning | <ul style="list-style-type: none"> • 2.3% of cane area burnt every year (i.e 1817 ha) • 500 kg/ha of particulate matter emitted |
| 3 | Inorganic fertilizer and herbicide Manufacture | <ul style="list-style-type: none"> • Energy required to produce herbicides = 190 MJ/kg • Fuel input in production of herbicides is 15% diesel, 70% coal and 15% electricity • Energy required to produce 1 kg of NPK fertilizer is 56.6 MJ • Fuel input in production of fertilizers is electricity, coal, diesel and natural gas |
| 4 | Transportation | <ul style="list-style-type: none"> • Cane transportation over an average distance of 7 km and diesel consumption of 0.075 litres/tonne km • Fertilizer and herbicide transport over an average distance of 20 km from harbour to field. • Sugar transport over an average distance of 60 km from factory to storage in harbour area. • Diesel = 37 MJ/L |
| 5 | Sugar Processing and Electricity Generation | <ul style="list-style-type: none"> • 50 Mm³ of water used for cane processing on the island • Pollutant loadings of 2.07 kg COD; 0.72 kg BOD₅ and 1.37 kg TSS per tonne of cane • 0.27 tonnes of molasses per tonne of sugar and 0.3 tonnes of bagasses per tonne of cane produced as by-products • 360 GWh of electricity exported to the grid, equivalent to 65 kWh per tonne of cane. • 500 kg of steam consumed per tonne of cane processed and electricity consumption of 22.5 kWh/tonne of cane • Bagasse ash production of 0.015 tonne per tonne of bagasse. |

2 Methodology

The methodology applied is LCA as described by Heijungs et al. (1992) and Guinée (2002) and according to ISO (1998). The impact assessment conducted in this study considers the following impact categories: Primary energy depletion, global warming, acidification, nutrification, photo-oxidant formation, human toxicity and aquatic toxicity. Two valuable by-products are produced during the production of one tonne of sugar: 0.27 tonne of molasses and 591 kWh of electricity through the burning of bagasse. The allocation is based on the commercial value of one tonne of sugar and molasses at Rupees (Rs) 11,000 and Rs 800 respectively, and the price of electricity sold at Rs 1.60/kWh (1 US\$=Rs30).

3 Results

3.1 Resource consumption and emissions

An important task of this study was to determine the resource consumption within the industry. Table 4 summarises the resource consumption and emissions in the production of one tonne of sugar.

Table 4: Resource consumption and emissions per tonne of sugar produced

| Resource Consumption | |
|--|--------------------|
| Land requirement | 0.12 ha |
| Water Consumption | 553 m ³ |
| Fossil Fuel Consumption | 1995 MJ |
| Total Energy Consumption (fossil fuel and bagasse) | 14235 MJ |
| Emissions to Air | |
| 1.7 kg TSP | |
| 1.21 kg SO ₂ | |
| 1.26 kg NO _x | |
| 1.26 kg CO | |
| 0.065 kg VOC | |
| 0.002 kg CH ₄ | |
| 0.260 kg N ₂ O | |
| 160 kg CO ₂ from fossil fuel use | |
| Emissions to Water | |
| 1.7 kg N | |
| 0.002 kg Herbicides (A.I.) | |
| 19.1 kg COD | |
| 6.3 kg BOD ₅ | |
| 13.1 kg TSS | |
| 0.37 kg PO ₄ ³⁻ | |
| 0.1 kg oil and Grease | |

The primary energy consumption per tonne of sugar throughout the life cycle is 1995 MJ. Results of the resource consumption of energy are shown in Fig. 2. Fertilizers and herbicides manufacture is a large energy consumer, 58%. The agricultural step (cane cultivation and harvest, and fertilizer and herbicide manufacture) accounts for 75% of the total primary energy consumption.

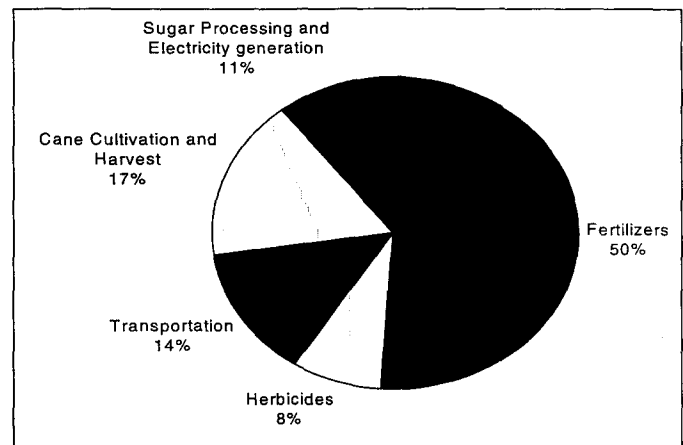


Fig. 2: Primary energy consumption by life cycle stages

3.2 Net CO₂ emissions

The production of sugar from sugar cane is related to greenhouse gases emissions in two main aspects:

- Since all the carbon in the sugar cane is recycled, sugar cane production will contribute to net CO₂ gas emissions only through fossil fuel inputs to agriculture and industrial processes.
- In Mauritian factories, steam cane (and co-generated electricity) is produced using bagasse as fuel. Around 360 GWh are being exported to the grid from bagasse, which is equivalent to around 65 kWh per tonne of cane.

So, the net savings in CO₂ (equivalent) emissions achieved in sugar production in Mauritius can be estimated by taking four components into account:

- The emissions due to fossil fuel utilization in the production of sugar cane and in sugar manufacture
- The methane emissions from sugar cane burning and the N₂O emissions from soil
- The avoided emissions due to bagasse substituting for fuel oil (or coal) in sugar manufacture (UNEP(1996))
- The avoided emissions due to the export of electricity, substituting for fuel oil.

Estimates of Emissions and Avoided Emissions are as follows:

- Emissions from fossil fuel utilization in cane and sugar production, emission from N₂O from soil and methane from sugar cane burning: 160 kg CO₂ / tonne sugar or 104 000 tonnes of CO₂ for the whole island.
- Avoided emissions from bagasse substituting for fuel oil in sugar manufacture = 1.343×10^6 tons bagasse leading to 0.23×10^6 tons oil or 0.73×10^6 tons CO₂
- Avoided emissions from electricity exported, substituting for fuel oil in other industries is 360 GWh, equivalent to 306327 tons of CO₂.

Therefore, the net avoided emissions = 932 327 tonnes CO₂ (equivalent). This corresponds to nearly 45% of all CO₂ emissions from fossil fuels on the island.

3.3 Relative significance of the different life cycle steps

The relative contributions made by the subsystems as well as the absolute, total contributions are summarized in Table 5 and Fig. 3. Cane cultivation and harvest accounts for the largest environment impact (44%) followed by fertilizer and herbicide manufacture (22%), sugar processing and electricity generation (20%), transportation (13%) and cane burning (1%).

The agricultural step (cane cultivation and harvest, and fertilizer and herbicide manufacture) accounts for two-thirds of the environmental impact of sugar production.

4 Discussion

4.1 The hot spots of cane-sugar production and possible improvements

The following can be concluded from Table 4 and Fig. 4, with respect to the contribution of each process to the impact categories considered in this study:

- Energy depletion – The primary energy consumption per tonne of sugar throughout the life cycle is 1995 MJ. The agricultural step (cane cultivation and harvest, and fertilizer and herbicide manufacture) accounts for 75% of the total primary energy consumption.
- Nutrifaction – Cane cultivation is the greatest contributor (67%) through the use of fertilizers. Emissions of COD during sugar manufacture accounts for about 29%.
- Acidification – Emissions of sulphur dioxide and nitrogen oxides are the key parameters contributing to acidification. The largest impact score belong to the subsystems of sugar processing and electricity generation, and fertilizer and herbicide manufacture.
- Global Warming – This impact category depends mostly on the use of fossil fuel energy. As fertilizer and herbicide manufacture is the largest energy consumer, its share is also the highest in this impact category. Agriculture (cane cultivation, and fertilizer and herbicide manufacture) contributes about 80% to this impact category.
- Photo oxidant – The highest degree of photo-oxidant formation is the transportation step (56%). The second most important contributor is cane cultivation and harvest (24%)
- Aquatic toxicity – Herbicide loss during cane cultivation is the sole contributor to this impact category.
- Human Toxicity – Sugar processing and electricity generation, with its emissions of fine particulates during bagasse burning is the main contributor (43%). The next main contributor is transportation (20%).

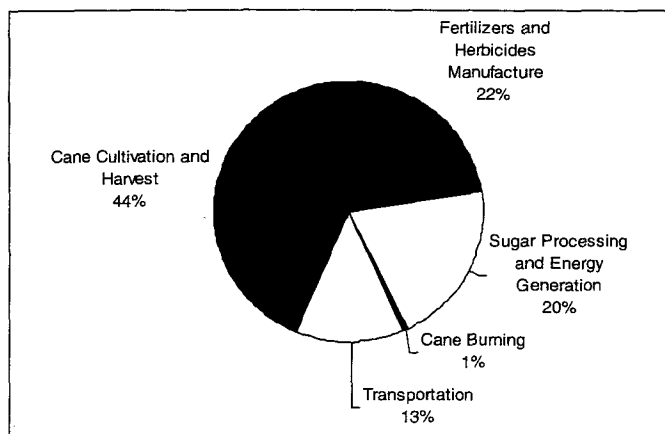


Fig. 3: Subdivision of the environmental index by lifecycle stages

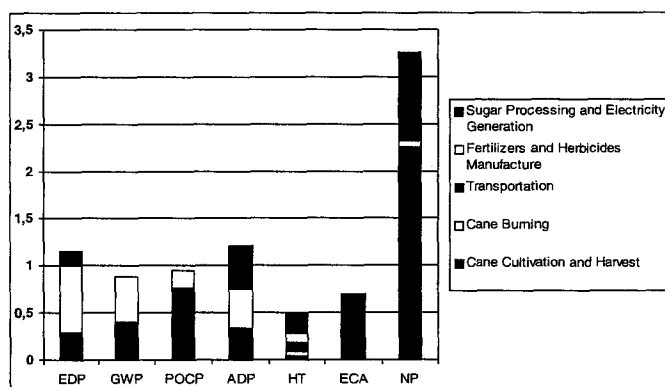


Fig. 4: Subdivision of the environmental index by impact categories and subsystems

As mentioned in other food industry LCA studies (Andersson and Ohlsson 1999), agriculture is a remarkable hot spot over the whole food processing system. This tendency is seen to be similar in the current results. Cane cultivation and harvest, as well as fertilizer and biocide manufacture, were found to be hotspots for most of the impact categories investigated. For the impact categories of nutrifaction and aquatic toxicity, it is clear that the cane cultivation system is highly significant owing to the nutrient and herbicide leaching, and ammonia emissions. Fertilizer and herbicide manufacture is highly significant in terms of primary energy consumption and global warming contribution. Only 36% of the fertilizer nitrogen applied to the soil is taken up by the plant in one year (Ng Kwee Kwong 1995).

Table 5: Relative contributions made by the sub-systems and the absolute, total contributions. The functional unit (FU) is defined as one tonne of raw sugar exported

| | Cane cultivation and Harvest (%) | Cane Burning (%) | Transportation (%) | Fertilizer & Biocide Manufacture (%) | Sugar Processing & Electricity Generation (%) | Total per FU |
|-------------------------|----------------------------------|------------------|--------------------|--------------------------------------|---|---|
| Primary energy | 10.3 | 0 | 14.7 | 61.2 | 13.8 | 1995 MJ |
| Global Warming | 35.2 | – | 10.2 | 54.5 | – | 233 kg CO ₂ equivalent |
| Acidification | 16.5 | – | 11.6 | 33.9 | 38 | 2.41 kg SO ₂ equivalent |
| Nutrification | 66.6 | – | 2.8 | 1.8 | 28.8 | 1.72 kg PO ₄ ³⁻ equivalent |
| Photo-oxidant formation | 24.2 | 0.1 | 55.8 | 20 | – | 0.024 kg C ₂ H ₄ equivalent |
| Human Toxicity | 8.2 | 10.2 | 20.4 | 18.4 | 42.8 | 2.2 kg (1,4 – DCB eq.) |
| Eco-toxicity | 1.00 | – | – | – | – | 10 kg (1,4 – DCB eq.) |
| Aquatic | | | | | | |

Precision farming involving a rational fertilizer management programme is not only cost effective, but also beneficial to the environment since it will greatly reduce the nutrification impact due to sugar production.

Water conservation and organic pollution control during sugar manufacture and electricity generation will also significantly reduce the nutrification impact of the industry. Sugar processing and electricity generation, with its emission of fine particulates in bagasse boilers, is the main contributor to human toxicity and effective policy measures for fly-ash control need to be introduced.

A centralisation process of sugar factories would decrease the haulage distance and hence a decrease in diesel use energy input. Also more cane at a given factory implies more bagasse on site and, hence, higher generating potential and more efficiency.

In relation to water consumption – an impact category not addressed in the present study – irrigation for sugar cane growing is a very large consumer of water. About 550 tonnes of water goes in the production of one tonne of sugar. In a water stressed country like Mauritius, effective irrigation systems and water policies need to be devised and implemented.

4.2 Impacts of relevance to developing countries

Existing methods for Life-Cycle Impact Assessments (LCIA) pay attention to impact categories which are associated with chemical emissions or to those which consider the input of energy and abiotic resources. Non-traditional LCA countries have a greater concern for categories such as land and water uses and biodiversity loss. Land-use, though it is considered to be an important impact category in agriculture, has been omitted or treated in a simplified manner both in methodological development and application of LCAs. Few LCAs address land-use since it is place specific and is not based on a mass or energy balance. There is presently no best available practice in this field of assessment and the impact category needs to be defined. Principles for how this can be done have been discussed by Mattson et al. (1998) and Lindeijer et al. (1998) among others. Land-use indicators tend to be limited to specific locations and are based on intensive ecological testing. The UNEP/SETAC Life Cycle Initiative is to address the methodological development of the specific impact categories of importance to developing countries such as land-use, salinisation, soil erosion and water use.

Sugar cane has been cultivated in Mauritius for four centuries. Other crops have been introduced, but without any success, and sugar-cane has integrated into its environment, resisting the harsh tropical climatic conditions (cyclones, droughts, intense precipitation events, etc.) and ensuring a permanent vegetation cover over the island which protects against soil erosion. It has also been instrumental in the development of the rural population. The structural change in the economy over the last two decades means that there is a decline in the acreage under sugar cane and an expansion of land use for urbanization and industrial purposes. Also, a centralisation process of sugar factories would lead to significant socio-economical impacts through the closure of some of the factories. The feasibility of combining the concept of sustainability principles and

the methodology of LCA in agriculture has to be examined so as to achieve an operational tool that can be used to incorporate both principles in strategic planning.

5 Conclusions and Recommendations

Based on the inventory analysis and impact assessment results, the main conclusions and recommendations on how to improve the environment performance of the cane-sugar industry, which resulted from this study, are as follows:

- The inventory of the current sugar production system revealed that the production of one tonne of sugar requires, on average, a land area of 0.12 ha, the production of 9.07 tonnes of cane, the application of 0.84 kg of a.i. herbicides and 16.5 kg of N-fertilizer, use of 553 tons of water and 170 tonnes km of transport services. The total energy consumption is about 14 235 MJ per tonne of sugar of which fossil fuel consumption account for 1995 MJ and the rest is from renewable bagasse. The agriculture step (cane cultivation and harvest, and fertilizer and herbicide manufacture) accounts for 75% of the total primary energy consumption.
- 160 kg of CO₂ per tonne of sugar is released from fossil fuel energy use. The net avoided emissions of CO₂ due to the use of bagasse as an energy source is about 932 000 tonnes, equivalent to about 45% of all fossil fuel emissions on the island.
- 17 kg TSP, 1.21 kg SO₂, 1.26 kg NO_x and 1.26 kg CO are emitted to the air per tonne of sugar produced. 1.7 kg N, 0.002 kg herbicides, 19.1 kg COD, 13.1 kg TSS and 0.37 kg PO₄³⁻ are emitted to water per tonne of sugar produced.
- Cane cultivation and harvest accounts for the largest environment impact (44%) followed by fertilizer and herbicide manufacture (22%), sugar processing and electricity generation (20%), transportation (13%) and cane burning (1%). The agricultural step (cane cultivation and harvest, and fertilizer and herbicide manufacture) accounts for two thirds of the environmental impacts of sugar production.
- Nutrification is the main impact followed by acidification and energy depletion. Nutrification is contributed by releases of NO_x in air during transportation, and fertilizer and herbicide manufacture, emissions of COD during sugar processing and nitrogen leaching during cane cultivation.
- Cane cultivation and harvest as well as fertilizer and bio-cide manufacture were found to be hot spots for most of the impact categories investigated. Greater emphasis should be laid on the time of application and weather conditions when formulating fertilizer use recommendation to farmers. Fertigation through drip irrigation systems allows reduction in fertilizer input, provided the water application rate is well monitored to avoid loss in drainage. Better management of residue recycling (filter cane, trash, fly ash) can lead to substantial reduction of mineral fertilizers and herbicides.
- Government should consider economic instruments instead of the present policy of uniform regulations based on discharge standards. The introduction of a resource tax to induce the development of water saving technologies and a pollution tax must be considered. There are no technical difficulties in reducing the average water consumption to 25% of the value practiced today.

- Factories need to be equipped with efficient fly-ash removal systems, and the enforcement and monitoring capacity of the Department of Environment in this area need to be enhanced.
- Implementation of more co-generation projects will enable the country to diversify its energy base, rehabilitate, modernise and centralise cane milling activities, save on fossil fuel impact and reduce the emission of greenhouse gases, mainly CO₂. Whilst bagasse is a very convenient energy source for sugar mills, it is generated in excess of needs and is therefore also burnt as a method of disposal. As a result, combustion efficiencies of bagasse boilers are quite low. Implementation of policies and incentives to encourage the sugar industry to efficiently use energy in sugar cane processing need to be considered. Such measures include the enhancement of the calorific value of bagasse, reduction in power consumption in the prime movers of sugar manufacturing equipment, reduction in process heat consumption in juice heating and evaporation, adoption of continuous processes, factory computerisation and process automation (Deepchand 2000).

Owing to events taking place at the international level, the sugar cane industry is at a cross roads. It has to undergo drastic changes to ensure its sustainability and competitiveness in the context of the globalisation of the economy. In the past, the sugar industry depended on sugar alone for its commercial viability. But energy projects from bagasse will play an increasing role in the revenue of the industry and become the core business interest. Energy production is also expected to increase in the future due to the possibility of green-cane harvesting and trash utilization as fuel.

Sugar production and processing is or will be subjected to agricultural, environmental and energy policies. LCA is a valuable tool for assessing the various policies so as to improve the environmental performance of the cane sugar industry in strategic decisions and to substantiate 'green energy' claims.

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